9 Frontier Agriculture: Climate-Smart and Water-Saving Agriculture Technologies for Livelihoods and Food Security

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Abstract

Many refugee and host populations are food insecure and poor. At the end of 2020, nearly 82.4 million people worldwide were forcibly displaced, and the United Nations Refugee Agency reported that more than 26 million people were living in refugee-like situations. The rapid and large influx of refugees adds additional pressure to host countries' water and public resources, which amplifies the need for more climate-smart and sustainable food production. There is an urgency to engage with and support refugee livelihoods.

This chapter shows that Frontier Agriculture, which comprises climate-smart and water-saving agriculture technologies, such as hydroponics and aquaponics, can contribute to improve overall well-being and nutritional status for farmers and groups of people that are less integrated into the labor market. Frontier agriculture can leverage scarce resources, such as water and arable land, and promote inclusive economic activities that increase access to nutritious food, improve livelihoods, create jobs, promote entrepreneurship, enhance skills, and build social cohesion. It can also assist with building communities and help recover from the loss of assets and from trauma of fleeing from conflicts. Previous experiences suggest that small-scale hydroponic and aquaponic projects targeting vulnerable populations can be implemented rather quickly and produce meaningful results within a short timeframe.

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9.1 Introduction

The Middle East and North Africa (MENA) is experiencing unprecedented levels of forced displacement. As many as 82.4 million people worldwide were forcibly displaced at the end of 2020, according to UNHCR.[1] The water crisis, coupled with fragility,[2] may fuel more migration and place more pressure on scarce water resources and land (World Bank 2017b). Migration can act as risk multipliers in fragile contexts.[3] The rapid and large influx of people adds additional pressure to host countries' water and land resources, amplifying the need for more climate-smart and sustainable food production.[4] Currently, agriculture uses nearly 85% of the water in MENA. While many farmers have implemented drip irrigation and other water-saving technologies in recent decades (World Bank 2017d), more innovation is needed to increase the production of and access to nutritious food using approaches that have not been exploited in the past.

Climate-smart and sustainable agriculture is important to achieve nutritious food security[5] and increase income-generating activities. Many refugee and host populations are food insecure and poor. Creating livelihoods and engaging in economic activities in the new environment are a challenge for those who have been displaced. Besides contributing to food security, water-saving agriculture technologies and innovations can provide jobs and livelihoods along with skills

[1] UNHCR (2021), https://www.unhcr.org/flagship-reports/globaltrends/.

[2] A fragile situation is defined as having either: (a) a composite World Bank, African Development Bank and Asian Development Bank Country Policy and Institutional Assessment rating of 3.2 or less; or (b) the presence of a United Nations and/or regional peace-keeping or peace-building mission (e.g., African Union, European Union, NATO), with the exclusion of border monitoring operations, during the past 3 years (World Bank 2019).

[3] Source: World Bank (2017b), Water Management in Fragile Systems, *Building Resilience to Shocks and Protracted Crises in the Middle East and North Africa.*

[4] According to FAO, climate-smart agriculture (CSA) is an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible. CSA is an approach for developing agricultural strategies to secure sustainable food security under climate change. CSA provides the means to help stakeholders from local to national and international levels identify agricultural strategies suitable to their local conditions. CSA is one of the 11 Corporate Areas for Resource Mobilization under the FAO's Strategic Objectives. It is in line with FAO's vision for Sustainable Food and Agriculture and supports FAO's goal to make agriculture, forestry, and fisheries more productive and more sustainable.

[5] Food security is a measure of (1) availability and (2) access of food (World Bank 2017c).

and human capital upgrading for both host communities and forcibly displaced populations.

Traditional growing methods are not effective solutions given the context of forcibly displaced populations and their lack of access to resources. Growing in the urban context would enable a shorter supply chain, less transport, less packaging, conservation, and labor needed, leading to substantial decreases of resources and energy use (e.g., up to 79% of the retail price in US conventional food distribution) (Wohlgenant 2014). Shortening and simplifying food supply chains can drastically diminish their environmental impacts, while providing cities and rural areas with fresh, highly nutritious produce.

Water and agriculture are key to stabilization and ultimately to peacebuilding through producing, processing, and selling food, generating income and employment, rebuilding household-level food security, and rebuilding social cohesion and institutions from the bottom up. Building resilience in water and agricultural systems in fragile and conflict-affected areas requires both the short- and long term to be considered in planning, bridging the humanitarian-development divide. World Bank (2017b) found that "when water quality and quantity are reduced, water for irrigation may be curtailed, leading to conditions that can breed fragility, such as rural unemployment, rural-urban migration, job competition and price inflation in urban areas, and consequent instability." Regions where a large portion of employment and livelihoods depend on irrigated agriculture are particularly exposed to these types of risks.

The rationale for mapping and analyzing the potential of "matching" Frontier Agriculture (FA) technologies with the needs of refugees and host populations in MENA is fourfold:

1. The food-water-energy nexus is important for recovery and stabilization of countries and communities. The core of this nexus is the need to establish food security for all individuals. These emerging agriculture technologies can potentially make an important contribution to reduce water use in agriculture (more crops per drop) and to increase well-being, food security, and resilience of vulnerable people, while also reducing multiple-dimension poverty. Moreover, agriculture is the first sector to recover from conflict situations because production inputs can be rapidly mobilized, including seeds, tools, and water.
2. Poor refugees and host communities are economically insecure and spend a large amount of time trying to meet basic needs. The return to skills from prior occupations and education is often low due to lack of jobs and economic opportunities. Policy simulations show that typical development policies that invest in skills, education, and employability are unlikely to succeed in improving welfare unless they are accompanied by more comprehensive measures aimed at creating adequate economic opportunities.
3. There is an urgent need to bridge the humanitarian-development divide and assist displaced populations to rebuild their active lives through concerted development efforts while also supporting host communities. When forcibly displaced populations do not have access to economic opportunities, their human and social

capital deplete, and they survive on short-term coping strategies, which include putting children to work, marrying off girls at a very young age, and disposing of their few assets.

4. The humanitarian system is under pressure and underfunded. The large-scale emergencies continue to drive increases in humanitarian assistance needs. Multi-sector requirements in UN appeals have increased 13-fold between 2005 and 2015. The pace of growth slowed between 2015 and 2016, with a 6% increase and appeals reaching US$27.3 billion in 2016, of which the UN-coordinated appeals accounted for US$20.5 billion and 40% of the requested amount remained unfunded. Several sectors are particularly underfunded, such as agriculture, education, and security. Moreover, there is a need to advance not only the social side, but also the economic and productive sectors, while shifting from providing humanitarian assistance to development assistance.

Within the broader frameworks above, this chapter analyses the potential of FA, and more specifically hydroponics for innovation and for development engagement that have a positive impact on the lives of refugees and host communities in the MENA region. This chapter begins by exploring the potential of FA (Box 9.1) to contribute to an improvement in well-being of displaced populations, including nutritional status, and analyzes which FA technologies are appropriate for different settings. Additionally, we further analyze how new and improved livelihoods, increased economic integration, and expanding markets can potentially reduce the burden of hosting a large number of refugees on host communities and countries while simultaneously providing opportunities for vulnerable host communities, including youth.[6] There is evidence from ongoing initiatives of hydroponics that this activity not only contributes to increasing skills and knowledge and improving livelihoods but can also assist in building communities recovering from the loss of assets and trauma of fleeing from conflict.[7]

[6] MENA is facing a youth bulge, and strategies are needed for integrating youth in the economy. Youth shares in MENA countries are typically higher than global averages, both as share among the total population and the working-age population. Yemen and Palestinian Authority have much higher youth shares in the latter category with more than 26% of the working-age population between ages of 15–24, compared to a global average of 19%. Moreover, as of 2016 only approximately one fifth of females over 15-years old is in the labor force, implying that women's labor force inclusion in MENA is the lowest in the world (source: World Development Indicators, 2016 World Bank).

[7] See https://www.weforum.org/agenda/authors/dorte-verner and www.enosh.org.il on an example of community building through hydroponics. World Bank (2017a): Forcibly Displaced. Towards a Development Approach Supporting Refugees, the Internally Displaced, and their Hosts. Overview, *notes (p1), "development actors should help reduce—even eliminate vulnerabilities. The forcibly displaced have often acquired vulnerabilities that are specific to them, such as catastrophic losses of assets and trauma.*" The issue is further discussed on p. 8 of the aforementioned report.

Box 9.1 Frontier Agriculture

"Frontier agriculture" is a term that encompasses climate-smart and water-saving agriculture technologies and comprises horticulture production applying hydroponic systems, hence growing vegetables with significantly reduced water usage (80–95%), minimal land area, and fewer inputs compared to traditional farming.

There are different types of hydroponic systems ranging from low to high-tech, including open and closed circulation systems. The most common systems are water culture, drip system, and nutrient film technique (NFT). Hydroponics can be installed in urban, peri-urban, and rural locations. The systems can be small, portable, and easy to manage and can be installed in homes, on roofs, and in other private and public spaces. People that have limited or no access to land and who cannot use traditional farming methods can be provided with opportunities to produce food with hydroponics.

Currently, hydroponics is mainly used to grow tomatoes, cucumbers, peppers, leafy greens, and a variety of specialty herbs and crops. Plants use equal amounts of water in hydroponics and conventional soil methods; however, a hydroponic system delivers water more efficiently to plant roots so overall water use is significantly reduced. Since the systems support production of fresh vegetables and herbs, they have the potential to positively impact household members' nutrition and household incomes through sales of fresh produce.

Source: https://www.weforum.org/agenda/authors/dorte-verner

The majority of refugees in the MENA region are facing poverty, food insecurity, and malnutrition. About 88% of refugees in Jordan are poor or vulnerable to poverty. Comparatively, in Lebanon, 71% of refugees live in poverty, with some districts reaching poverty rates of 80%. In both places, refugees are younger and there is a larger share of female household heads than in the host country. A significant share of Syrian refugees in Jordan and Lebanon are not only food insecure but have experienced deterioration of their dietary quality and reduction in the number of daily meals. In Jordan, 48.7% of the PAs[8] (Principal Applicants) reported reducing food quantity, 45.7% skip meals, 42.5% limit size at meals, 27.2% purchase food on debts, and 17.9% borrow food or rely on help from friends and/or neighbors. Refugees in Lebanon are also subject to significant food insecurity, and the data show that 89% experience reduced food quality, 61.4% skip meals, 46.2% reduced food quantity, 38.7% borrow food or rely on help from friends and/or neighbors, and 6.1% reported that women in the household eat less than men (Verner et al. 2017).

Different nutritious food items are not consumed by refugees on a regular basis due to shortages of nutrient-rich foods such as fruits and vegetables, eggs, and meat.

[8] "Principal Applicant" is defined as the primary applicant on a petition, in this case on a petition for refugee status.

The average number of days per week that refugees in Jordan reported going without access to specific food items was as follows: deprived of oils and fats about 5 out 7 days and deprived of eggs, dairy, cereal, pasta, canned food, and vegetables about 3 out of 7 days. Notably, there was no difference based on the PA's occupational background. Lack of sufficient nutritious food can affect refugees' health outcomes—and is especially critical for children as it affects brain and general development.

The main objective of this chapter is to increase the knowledge of Frontier Agriculture—water-saving, soilless, climate-smart agriculture technologies—that can increase nutrition and food security, economic engagement, and livelihoods and skills for disadvantaged refugee groups and their host communities. The analyses focus on situations in the MENA region. This chapter introduces two forms of soilless climate-smart agriculture: hydroponics and aquaponics and discusses the different types and adaptability and the requirements of the technology for different environments. It ends with a summary of the potential for Frontier Agriculture technologies to contribute to increased livelihoods and incomes of refugees and host communities.

9.2 Frontier Agriculture Technologies

In MENA, a shift from immediate, reactive responses to a balanced, long-term development approach is necessary to address the water and fragility challenges (World Bank 2017b). There is a vicious cycle of water and fragility due to their compounding nature. Water scarcity challenges are becoming worse with climate change, rising demands, inter-sectoral competition, and urbanization. FA water-saving technologies not only help address food security and meet other basic needs, but also reduce water scarcity issues and conflicts by leveraging the opportunities and productive potential of water.

Several initiatives have been launched to address challenges of limited arable land and water resources through soil-based farming methods, such as small plots, community gardens, and drip irrigation gardens. This chapter goes beyond addressing limited arable land and water resources through soil-based farming methods, such as small plots, community gardens, and drip irrigation gardens. Hydroponics and aquaponics technologies require less water, no soil, and minimal use of land. Hydroponics may be a valid alternative to produce nutritious food while increasing livelihoods in a natural resource-constrained environment.

The following sections describe water-saving agriculture technologies, namely different types of hydroponic and aquaponic systems, ranging from simple, low-tech to more advanced techniques. It covers the inputs and outputs, different aspects of production, and the costs and labor involved in these technologies. There is a special emphasis on simplified hydroponic and aquaponic systems.

9.2.1 Hydroponics

Hydroponics is a method of growing plants using a nutrient solution, which is a mixture of water and nutrient salts, without the presence of soil (Gericke 1940, 1945; Hoagland and Arnon 1950). Hydroponics is not a new phenomenon; early examples of hydroponic growing include the hanging gardens of Babylon and the floating gardens of the Aztecs of Mexico (Resh 1995). In traditional farming, soil is the main input to store the various nutrients required for plant growth. When water saturates the soil, it picks up these nutrients, so they can more readily interact with the plant roots (Campbell and Reece 2002). In hydroponics, soil is replaced with the use of a nutrient solution.

Hydroponic systems use 80–95% less water than open field agriculture, with more advanced systems using less water than simplified systems (Despommier 2010). Hydroponic techniques range from simple systems that do not need electricity and deliver water to buckets using only gravity, to sophisticated systems, that are stacked vertically in tall buildings requiring a power source to pump and circulate water, such as aeroponics. Hydroponic farming is possible across diverse climates and agro-ecological zones, including arid areas (Heredia 2014). Growing in more extreme environments can be done by farming indoors or in greenhouses in a controlled environment. These farming methods separate the production area from the ecosystem and greatly reduce the land area required for agricultural production, thereby lessening the impacts on ecosystem services (e.g., biodiversity, habitat, carbon sequestration, building soil, water purification, etc.) compared to traditional agriculture. Thus, hydroponic food production can have a positive impact on the environment and on natural resource management.

Hydroponic farming is being established in both urban and rural areas as consumer demands increase for fresh produce with high nutritional value. Since hydroponic systems do not depend on external conditions, they can be set up almost anywhere, including unused or recycled spaces such as parking lots, building rooftops, warehouses, and shipping containers. Producing in urban areas minimizes the distance between the food producer and consumer (Bellows et al. 2004).

9.2.2 Types of Hydroponic Systems

There is a continuum of at least seven types of hydroponic systems, from the most simplified to the most sophisticated types. From simple to advanced, systems include wick systems, deep water culture, ebb and flow, drip method, nutrient film technique (NFT), aeroponics, and aquaponics. The type of system chosen depends primarily on the type of plant as well as any limitations of the grower and/or growing space (Jensen 1997). While these system types may share many features, including design, they fundamentally differ in how they manage the nutrient solution. The most popular are water culture, drip system, and NFT (Resh 1995). Figure 9.1 compares the different types of systems and their advantages and disadvantages.

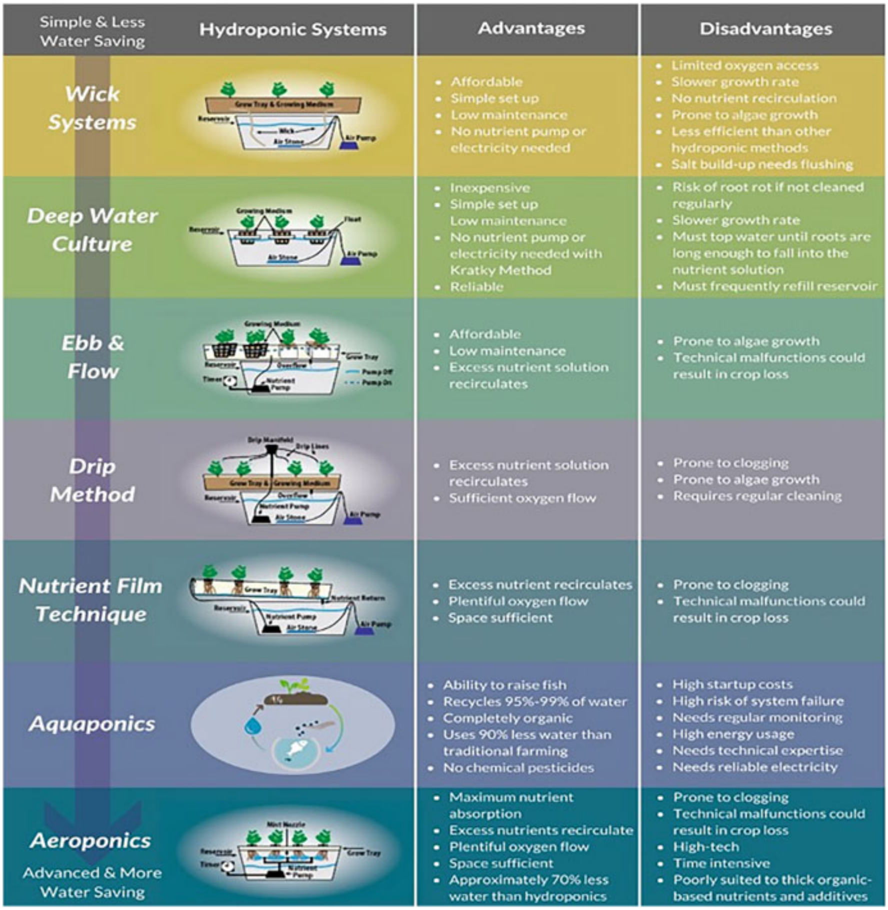

Fig. 9.1 Types of hydroponic systems and advantages and disadvantages. (Source: Authors)

Hydroponic systems can generally be delineated into open and closed systems (Abd-Elmoniem et al. 2006; Jensen 1997). Open systems, also known as "run to waste systems," do not employ water reuse measures; and the nutrient solution flows through the system only once and is discarded (Jensen 1997; Nederhoff and Stanghellini 2010). On the other hand, closed systems reuse the nutrient solution via recirculation for an unspecified length of time (Lykas et al. 2006). Open systems provide two primary advantages: they eliminate the need for nutrient solution maintenance and reduce the risk of plant pathogens and infection (Jones Jr. 2005). Despite these advantages, open systems are known to waste a large amount of water and nutrients (Nederhoff and Stanghellini 2010) and may not be appropriate for arid regions. In a closed system, more water and nutrients are added to top-up instead of replace the entire solution (Jensen 1997; Nederhoff and Stanghellini 2010). The nutrient solution is regularly monitored and adjusted to maintain proper nutrient ratios. As a result, closed hydroponic systems use 20–40% less water and nutrients than open hydroponic systems. However, they are more difficult to monitor and maintain, which arises from ion accumulation as the nutrient solution recirculates (Lykas et al. 2006). Also, recirculation requires an infrastructure of reservoirs and pumping systems that have to be monitored and maintained in order to perform optimally, which can make them more susceptible to failure if not managed well (Nederhoff and Stanghellini 2010).

9.2.3 Hydroponic and Aquaponic System Inputs

The main inputs to hydroponics are the seeds or seedlings, nutrient solution, water, growing medium, container, and, in some cases, electricity and lighting. Aquaponics will have fish fry and fish food in place of a nutrient solution. A more thorough demonstration of the inputs and outputs of hydroponics and aquaponics is shown in Fig. 9.2.

9.2.3.1 Wick Systems

The most simple, low-tech hydroponic systems are wick systems, which are non-circulating systems comprising raised garden beds that have a water reservoir below the plant roots. Water is supplied through a pipe to the water reservoir and the water is drawn upward into the root zone by capillary action, enabling the plants to absorb the amount of water they need. Therefore, there is no need for overhead watering and a lot less water is lost through evaporation. The roots growing in the moist soil have a continuous supply of water, oxygen, and nutrients.

The wick system technique works well in dry, water-scarce environments with limited and unreliable technical inputs, such as electricity, and where technical assistance is not readily available. For example, this technique is currently being used by women in the Palestinian Territories despite the challenges faced by the territories to access materials and inputs (Box 9.2, Fig. 9.3).

Box 9.2 Wicking Bed Systems in the Palestinian Territories

In March 2012, the Applied Research Institute Jerusalem (ARIJ), in partnership with the Polish Center for International Aid, piloted a project to adopt Nutrient Film Technique (NFT) and wicking bed production to increase food security, nutrition, women empowerment, income generation, and the competitiveness of the agricultural cooperatives sector in Palestine. Thirty-five NFT units and 52 wicking bed units were established to benefit marginalized and underprivileged families in remote areas of Bethlehem and Hebron governorates. Education models were also established at Al-Arroub Agricultural School to train students in these technologies. The student's families consume the food produced and the surplus is marketed to generate income

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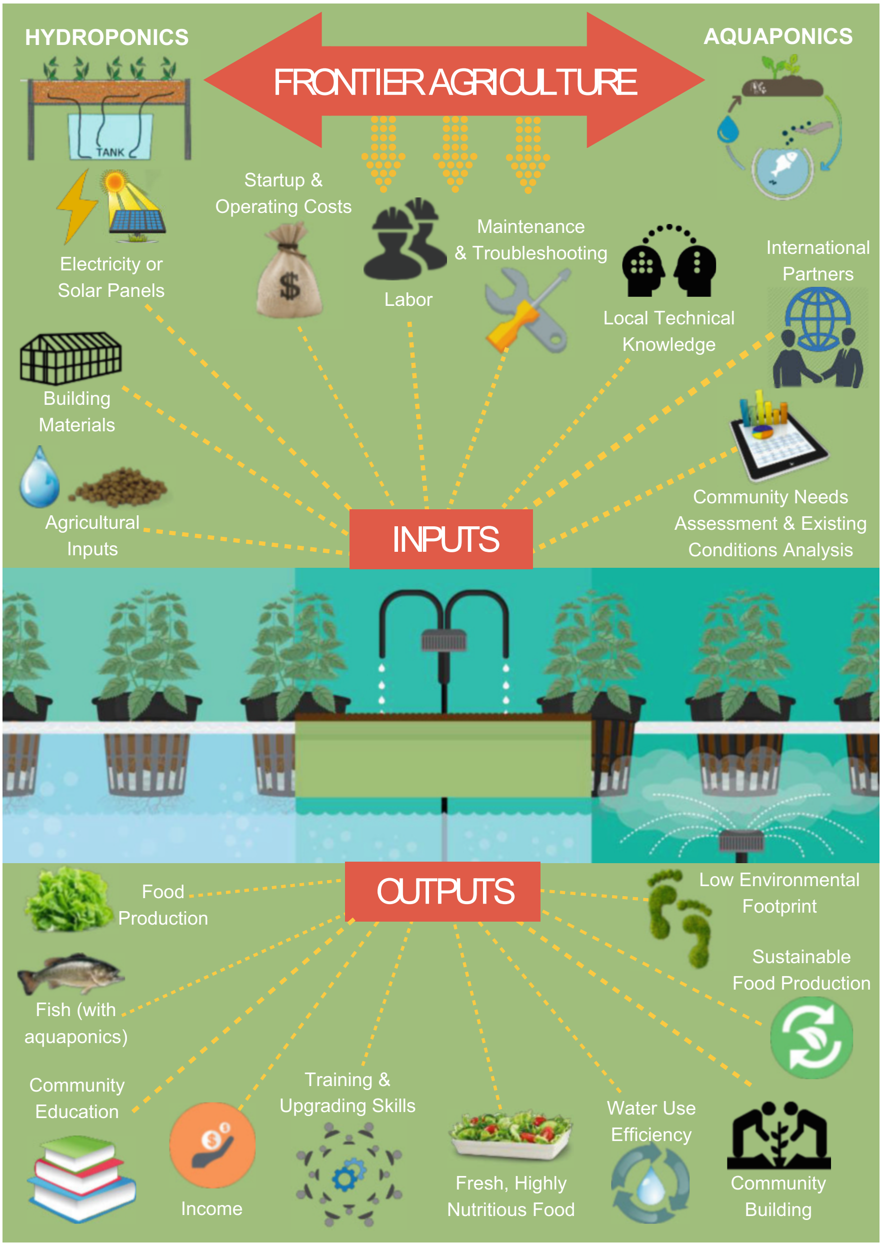

Fig. 9.2 Inputs and outputs of hydro/aquaponics. (Source: Authors)

Box 9.2 (continued)
and assist collaborating cooperatives in sustaining their social and humanitarian missions.

Each wicking bed unit kit costs US$820, which contains four beds with a total area of 4-square meters and can plant 200 seedlings per season for three to four seasons per year. Six hundred to 800 plants can be grown to produce 450–600 kg of food per year; thus, one hydroponic unit can produce food with a market value of US$400 to US$550 per year. Each wicking bed unit comprises four separate units that can be replanted three to four times a year, yielding the same production capacity as the NFT system. The project beneficiaries, who are mostly women, were trained to manage the units, which comprise of water pumps, a pumping regulator, and various fittings, such as pipes and other simple equipment. ARIJ provides training, technical support, and follow-up services to the beneficiary families.

Both NFT and wicking bed systems, which are portable, are suitable for urban and rural areas, particularly water-scarce environments, and reduce the usage of irrigation water by 50%. In addition to being safe and pesticide-free, the systems are conducive to family participation in planting and caring for the plants. These systems enhance food security at the household level for vulnerable populations and there is potential to transform these pilot units into a means of income generation.

9.2.3.2 Deep Water Culture

Deep Water Culture (DWC) is another simple, non-circulating hydroponic technique suitable for areas with little to no electricity. The system requirements include a water reservoir to supply nutrients to the plants and a polystyrene platform to float the plants on top of the nutrient solution. Water culture systems are highly desirable to grow leafy greens, such as lettuce, because these plants grow fast and consume large amounts of water.

The Kratky Method (KM) is a type of water culture where the farmer builds or uses a watertight container as a water reservoir, such as five-gallon plastic storage containers or trash bins, filled with the nutrient solution (Fig. 9.4). The KM is simple to operate, requires little to no maintenance, is inexpensive, and is suitable for inexperienced farmers. Plants are grown in net pots on top of the tank cover and are continuously watered since the entire growing medium becomes moistened by capillary action. The roots of the plants are only partially submerged in the water and the top of the plant roots has access to oxygen, creating a moist air. Aside from planting or transplanting, no additional labor is required until harvesting. Electricity and pumps are not needed, so the additional production costs and complexities associated with aeration and circulation in many other hydroponic systems are avoided by this method (Kratky 2009).

Fig. 9.3 Wick system. Photographs © Applied Research Institute–Jerusalem. Used with permission from Applied Research Institute–Jerusalem

9.2.3.3 Ebb and Flow

The ebb and flow method, also called flood and drain, is the classic hydroponic method that is widely used due to its inexpensive cost, dependability, and simplicity—although it does require a power source. This method feeds plants by flooding the plant site with a nutrient solution and allowing that solution to drain back into the reservoir. It uses pots filled with inert media, placed inside a tray or container. During the growing cycle, the tray or container is filled automatically several times a day by a pump that uses a timer.

9.2.3.4 Drip Method

The drip system is another widely used hydroponic technique with water circulating through the system using drip emitters. The drip emitters drip water rather than spray or run it, and a dripper runs to every plant placed in a growing medium. After the water passes through the cup holding each plant, it goes back into the water reservoir

Fig. 9.4 The Kratky Method bucket system. Photograph © Eyal Barkan/FARM-IT. Used with permission from Eyal Barkan

and gets recycled through the system again. Plants can be grown in buckets or trays. The system requires electricity to power a submersible pump to disperse the water and an air stone to mix the water in the reservoir.

9.2.3.5 Nutrient Film Technique

The Nutrient Film Technique (NFT) is a method that places plants in long plastic grow trays with water circulating through the system. Plants are then supported in smaller plastic net cups filled with a growing medium. A water level is set in the tube depending on the maturity of the plants. When the plants are younger, the water level is set higher allowing the roots to reach the water. Once the plant roots mature, the water level is lowered to promote root growth. With this technique, the nutrient solution is pumped past the plant roots allowing the plants to meet their water and nutrient requirements. The drawback of this system is that it is susceptible to power outages and pump failures. Once a failure occurs, the plant roots dry out very rapidly.

9.2.3.6 Aeroponics

Aeroponics is a relatively new method for growing edible plants and the most advanced method of hydroponics. Aeroponics utilizes a fine mist of nutrient-laden water created by its passage through a pressurized nozzle that is then directed toward the enclosed root system of the plants. Aeroponics uses approximately 70% less water than hydroponics, while delivering the same amount of nutrients to the roots. Recent advances in nozzle design have improved the reliability of the system for creating the spray by eliminating clogging due to nutrient build-up, a major issue in earlier models. As a result, more vertical farms are adopting aeroponics as their main growing strategy. See Box 9.3 for more information on vertical farming.

Box 9.3 Vertical Farming

Vertical farming allows produce to be grown in vertically stacked layers, on vertically inclined surfaces, or integrated in other structures, increasing productivity in terms of the amount of produce grown per square meter (Christie 2014). Vertical farms are a space-saving form of controlled environment agriculture and different types of hydroponic systems can be used to grow produce vertically. Vertical farms can range from simple NFT hydroponic systems using recycled materials to multistory buildings using aeroponics, such as AeroFarms in the USA (Fig. 9.3), containing an environment conducive to the growing of fruits, vegetables, and nonedible plants for biofuels, drugs, and vaccines. Today, the leading countries employing vertical farms include Japan, Singapore, Taiwan, China, the USA, and a few countries in Western Europe.

Vertical farming works well for small spaces including in urban settings such as rooftops and unused spaces. It allows for a higher yield to be obtained per square foot and uses less land than traditional farming. Vertical farming is more of a structural technique than an actual agricultural system since both hydroponics and other types of water and soil-saving techniques can be set up vertically. For example, vertical hydroponic gardens in Israel utilized NFT with a snake-like structure (Fig. 9.5), and a vertical triangular structure for a hydroponic garden in Palestine utilized NFT, but with a lower-tech set up and lower-cost materials (Fig. 9.5). Another vertical garden system in the Palestinian territories was constructed of recycled large water bottles and soil for production of small plants and herbs (Fig. 9.5).

9.2.4 Aquaponics

Aquaponics is a method for producing food that combines recirculating aquaculture, raising fish and aquatic animals in land-based tanks with hydroponics, cultivating plants in water. Aquaponics recycles 95–99% of the water introduced in the system and it is this recycling of water that distributes nutrients throughout the system. Aquaponics systems produce the same types of plants as hydroponic systems, but also provide protein by growing various types of fish and aquatic animals as demonstrated in Fig. 9.6. Depending on the type of system, aquaponics often uses less water than hydroponic systems, with the exception of aeroponics. Since fish plays a key role in the system and would die with the use of chemical pesticides, aquaponics grows chemical-free, all-natural produce.

Aquaponics is scalable and adaptable to many different uses: it can be used as a small or large-scale commercial farm, a recreational or hobby activity, for

Fig. 9.5 Examples of vertical farming approaches. Top left and top center: hydroponic example in Israel. Bottom left and bottom center: hydroponic example in Palestinian Territories. Right: hydroponic example at AeroFarms. (Source: Authors (left four images) and AeroFarms (right image))

community-based projects, as a hands-on teaching tool in the classroom, and can be incorporated with school curricula. The size of an aquaponic operation ranges in scale from a table-top fish tank to a large warehouse. The three main types of aquaponic systems incorporate deep water raft culture, media beds, and NFT. Deep water culture is most popular among commercial producers while media beds are most popular among home gardeners. Box 9.4 describes how aquaponics is used in the Palestinian Territories to increase food consumption, increase livelihoods, empower women, and address food security.

Box 9.4 Aquaponics in the Gaza Strip, Palestinian Territories

In response to the crisis in Gaza and given the high number of food insecure female-headed households in urban areas, the FAO has been implementing several small-scale aquaponics projects in partnership with European donors since 2010. In the first phase of their initial project, 119 food insecure female-headed households were provided with innovative vertical rooftop units connected to fish tanks. With little daily physical effort and in the comfort of carrying out these activities in their own homes, all the beneficiaries increased their household food consumption (FAO 2016). Aquaponics enabled women

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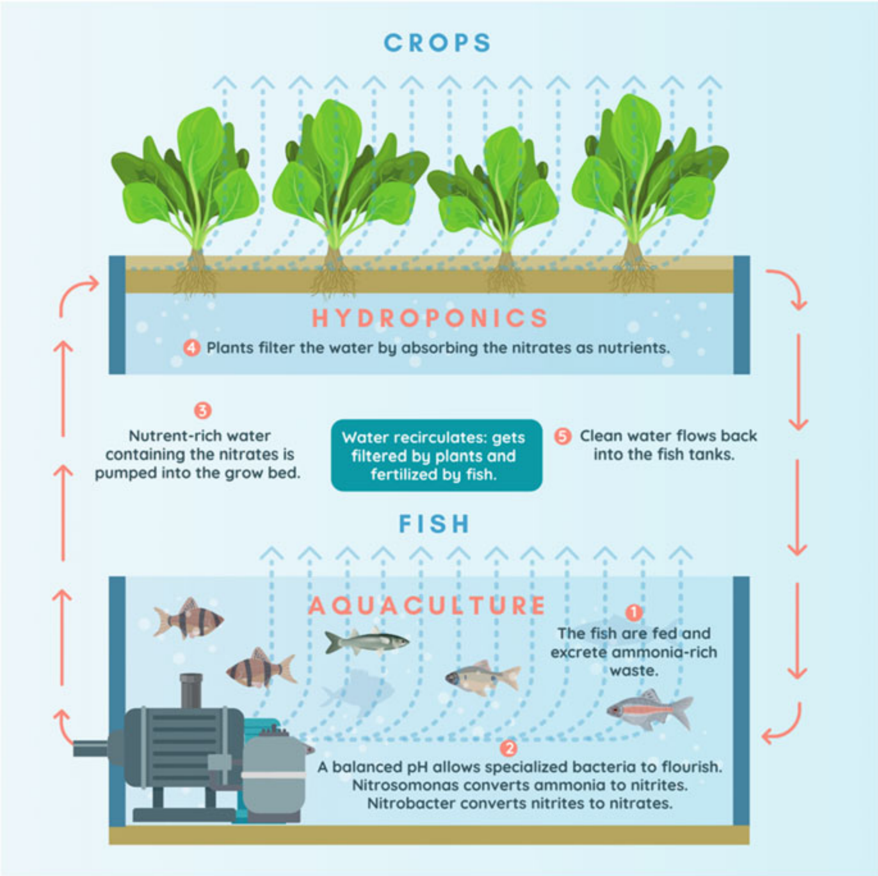

Fig. 9.6 The aquaponics cycle. (Source: Authors)

Box 9.4 (continued)

to simultaneously improve their food security and income while caring for their homes and children.

An aquaculturalist and supplier of fish to the FAO based in Beit Lahiya expanded his small aquaculture farm by integrating a semi-commercial sized plant production component to his operation. He effectively transformed his livelihood and created the largest aquaponics unit in Gaza (FAO 2016). The FAO is closely monitoring his progress and providing technical support when necessary as this initiative sheds light on the potential for vulnerable farmers in Gaza to generate income in semi-commercial aquaponic systems (FAO 2016).

9.2.4.1 Types of Crops

The ability to produce certain crops depends on the size of the growing system. In smaller spaces, such as for domestic use, crops such as leafy greens and herbs are common. Such plants grow quickly, can be continuously harvested, and do not require much space to expand. In larger spaces, such as a greenhouse, garage, or patio, a more advanced system may be used, and voluminous plants can be grown that require trellises and deep root support.

In commercial hydroponics, some crops do better than others. Tomatoes, lettuce, bell peppers, and cucumbers do very well in large-scale greenhouse facilities. Herbs and leafy greens do well in warehouse facilities that are vertically oriented. The quality and number of crops that can be produced will largely determine the viability of the commercial hydroponic operation.

Currently, hydroponics is mainly used to grow leafy greens, tomatoes, cucumbers, peppers, herbs, and several other crops (Spensley et al. 1978; Brentlinger 1997; Jensen 1999). These crops have demonstrated the revenues required to make a hydroponic operation profitable (Jensen 1999). Vegetables with both a vegetative state (leaf, root production) and a generative state (fruit production) were found to grow much more efficiently in soilless culture.

9.2.4.2 Nutrient Solution

The main input in hydroponics, the nutrient solution, is a combination of water and nutrient salts mixed to specific concentrations to meet plant requirements and ensure healthy plants (Hoagland and Arnon 1950; Graves 1980; Jones Jr. 2005; Resh 2013). The nutrient solution is fully controllable and can be delivered to plants on an as-needed basis. This makes hydroponics capable of high yields while minimizing water usage and nutrient consumption.

Maintaining an optimum pH range between 5 and 7 is essential since there is no soil to act as a pH buffer. Nutrient solution pH is a common parameter used in hydroponic growing. The pH of the root zone effectively determines which nutrients are available to the plant, as plants can only uptake certain ions within a specific pH range. Nutrient solution is not used in aquaponics, rather, the fish effluent provides fertility to the plants. Balancing pH for fish health is also critical.

9.2.4.3 Water

By volume, water is the primary ingredient in a nutrient solution and, therefore, the single most important factor to growth (Graves 1983). Plants consume equal amounts of water in hydroponics and conventional soil methods; however, the hydroponic system delivers the water more efficiently (Sanchez 2014). Hydroponic farming, in closed systems, uses 80–99% less water than conventional irrigated farming since the plants only consume the water they need while recycling the unused water back to the reservoir.

In rain fed agriculture, however, these comparisons become more difficult because rainwater cannot be "wasted" or "saved"—it is merely part of the hydrological cycle (e.g., evaporation, condensation, and precipitation). On the other hand, when plants are grown indoors or in greenhouses, water is not lost to deep percolation, runoff, and evaporation (Heredia 2014). Other variations and more advanced forms of hydroponics, such as aquaponics and aeroponics, use less water than simpler hydroponic systems (Pantanella et al. 2010).

9.2.4.4 Growing Mediums

The most widely used growing medium is rockwool, which is a melted balsamic rock spun into fibers. However, once used for growing vegetable crops, the disposal cost in landfills can be excessive as rockwool is biologically non-degradable. A replacement to rockwool that is becoming increasingly common is coconut coir, the husk of coconuts, which is found between the hard, internal shell that contains the coconut meat, and the outer coat of a ripe coconut. It is a renewable resource unlike peat moss, which is considered a non-renewable resource. In warmer regions of the world, peat moss biologically breaks down rapidly while coco coir is slow to decompose. Other popular options for growing media are perlite and/or vermiculite, often mixed with peat moss, as a growing medium in the production of greenhouse vegetable crops, especially in the production of vegetable transplants. Sand, gravel, and sawdust are also artificial media options. Sand is quite popular in arid/semi-arid regions of the world and sawdust in the forested regions of northern latitudes.

9.2.4.5 Energy Use

Addressing energy needs is one of the key challenges facing the hydroponics and aquaponics industry, particularly in northern latitudes. High-tech hydroponic systems tend to have high energy use due to incorporation of lighting, pumping, and air moderation systems. But, energy use for hydroponics can be part of a renewable energy use strategy for cutting down carbon emissions. Electricity can be sourced from wind or solar systems with a commercial battery to store excess renewable energy when needed.

When farming indoors and in greenhouses, most of the energy use in hydroponic farming can be attributed to the heating and cooling loads as well as supplemental artificial lighting. For example, heating is a major component of operational costs for greenhouses in northern Europe and other countries with cold winters. Greenhouses located in more moderate climates, such as climates closer to the greenhouse set point temperature, will experience a lower energy demand. In fact, in certain climates, heating and cooling systems may not be required, but instead replaced by a passive ventilation system, thus reducing the overall energy demand considerably. The feasibility of hydroponic systems is heavily reliant on the climate of farming locations (Barbosa et al. 2015). Though lighting increases the energy use, artificial light in indoor environments can make hydroponics feasible in areas with unreliable access to sunlight due to seasonal conditions or the surroundings.

For aquaponics systems, depending on the climate, type of system, and species of fish, there can be additional energy requirements to heat, aerate, and pump the water in fish tanks. Air stones and sprayer bars can help to aerate the water, and systems in warmer climates may not need to heat the water. Additionally, biodigestors may provide a more sustainable source of heat.

9.2.5 Production

Hydroponics allows for continuous production year-round in many areas and, on average, more annual growing seasons and shorter harvest cycles than soil-based farming methods. Hydroponic farmers have learned to adopt new growing methods and shifted away from traditional cultivars to achieve higher yields (Christie 2014). The productivity and hence economics of hydroponic food production continue to be main drivers for expansion. Today, commercial hydroponic farms can produce three to four times the yields compared to soil production while using significantly less water (Ly 2011). These higher yields result from the controlled environmental conditions maintained within the greenhouse or indoor farm, which allow for continuous production year-round. The controlled environment promotes a reduction in the number of days required for each harvest cycle, allowing for multiple crops per year. Also, plants grown hydroponically are generally less stressed than soil-grown plants since the plants are in their optimum growing conditions all the time, and in turn create less waste than conventional farming (Treftz and Omaye 2015). In aquaponic systems, fish stocking densities and thus production levels are constrained by the oxygenation levels of the tanks. One conservative estimate of the amount of fish that can be produced in a year is seven tilapia fish per 38 l of water (Goodman 2011).

9.2.5.1 Nutrition

The amounts of key nutrients in hydroponic produce are the same as in conventionally grown produce and are sometimes even higher reference. In conventional farming, plants obtain nutrients from soil, whereas in hydroponics, plants obtain nutrients from a solution instead. Plants generate their own vitamins; therefore, vitamin levels tend to be similar whether a vegetable is grown in soil or hydroponically. However, the mineral content can vary in hydroponic crops, which depends on the fertilizer used. The nutrient levels of a plant can be enhanced by simply adding nutrients to the solution, such as calcium, magnesium, or minor elements such as zinc or iron. Nevertheless, the nutrients and phytochemicals slightly vary for different crops in general, regardless of the growing method. The nutritional profile of each crop depends on the crop variety, the season it is harvested, the length of time between harvest and consumption, and how the crop is handled and stored during that time. These minor variations in nutrient levels are unlikely to have a significant impact on overall consumer health.

9.2.5.2 Pest Management and Plant Survival

Hydroponically grown plants, though not immune, are usually more pest resistant than plants grown using soil and may not need application of herbicides or pesticides. Plants grown in hydroponics are generally stronger and healthier than their soil-grown counterparts since they are fed precise nutritional requirements in a carefully controlled environment. In addition, natural preventative measures against infestations are implemented in most hydroponics systems. For example, companion planting is one method commonly used in hydroponics where crops are intermixed with plants that act as pest deterrents for the primary crop. Biological controls such as beneficial insects may also be used.

According to a study that compared hydroponic and soil systems for growing strawberries in a greenhouse, the hydroponic plants had a higher survival rate at 80% compared to the soil-grown strawberries, of which less than 50% survived (Treftz and Omaye 2015). The lower plant survival rates from soil-based farming are attributed to increased pest infections. Although both growing systems received identical integrated pest management treatments, the in-soil plants suffered more, and pests thrived in the soil-grown strawberries, particularly aphids and spider mites. This is due to increased beneficial bacteria and microbes that pests thrive on in soil conditions (Resh and Howard 2012). Although the hydroponic plants were affected by pests, to a lesser extent, the pests were not able to thrive in hydroponic conditions (Treftz and Omaye 2015).

9.2.5.3 Cost and Labor

Hydro/aquaponic systems vary in terms of cost and labor depending on the system and the materials used, as well as local factors such as climate conditions and energy costs. The startup costs of a hydro/aquaponics system are usually higher than the cost to set up a soil-growing operation. Some of the startup costs of a hydro/aquaponics system can be offset with reduced operating costs due to the system's efficiency in the use of labor, water, fertilizers and pesticides. Also, there tends to be less waste with hydro/aquaponics compared to soil-growing operations.

Startup costs of a hydroponic greenhouse can range anywhere from 2 to 20 times more than soil agriculture (Mathias 2014). When including the hydroponic growing system, estimated costs for greenhouses range from US$52 to US$140 per square meter in research conducted in the 1990s in the USA (Jensen and Malter 1995). Commercial operations may also require a warehouse or other building or structure (Pantanella et al. 2010), which may create added startup costs. Some commercial hydroponic operations require controllers, computer systems, large-scale lighting fixtures, ventilation and heat recovery systems, irrigation and rainwater harvesting, as well as skilled labor (Pantanella et al. 2010). Electricity and utility costs can also be extremely high.

Non-commercial and simpler systems that use existing local materials can cut startup costs considerably, and can be beneficial where imports are expensive or specific technology and materials are unavailable. One wicking bed system in the Palestinian Territories costs $820 for four beds, growing materials, and a simple grow structure of shadow nets with iron skeleton and plastic sheeting for weather and sun protection. Lower-cost solutions, such as simplified, lower-tech variations of the technology are increasingly being implemented in developing countries, particularly those with an arid landscape and water scarcity, such as Jordan.

Labor costs for hydro/aquaponic systems vary depending on the complexity of the system chosen, the amount of trained labor required, and local technical knowledge. Despite this variability, labor costs for a hydro/aquaponic system represent a much larger share than traditional farm labor, which is estimated by the USDA to vary from 17% to 40% of total operating costs in labor-intensive farm production (Daly and Fink 2013), and for hydro/aquaponics systems could be has high as 56–70% (Goodman 2011). In a commercial system, in order to lower labor costs and keep them at an even rate, automated technology may be beneficial.

In terms of labor requirements, the more sophisticated the system, the more technical expertise is needed to monitor and troubleshoot when problems arise. Hydroponic growers must know technical details about the species being produced, plant health problems and how to fix them, symptoms of nutrient deficiency and toxicity, management of nutrient solution, anticipation of possible power outages, and the consequent lack of water circulation in the channels. Aquaponics systems have additional labor requirements related to animal husbandry, water quality, and simple plumbing concepts. Examples from Jordan, Palestinian territories, and the UAE show that the required skills and techniques can be rapidly acquired for people with little formal education.

9.2.5.4 Income and Profitability

When planning a hydro/aquaponics system, it is challenging to estimate production levels and income as production varies greatly from system to system and climate to climate. Further, income is influenced by the type of crops that can be grown, local demand, and food prices. Local food prices may shift dramatically over time, allowing producers to charge higher or lower prices for their product (Goodman 2011). In an aquaponics system, it is less possible to quickly change the aquaculture component to adjust to market conditions; the systems can be finicky, can fail, and often are not profitable enterprises. It is advisable to use conservative estimates to account for mishaps with the system and unsold produce (Engle 2015). Notwithstanding these challenges, there is a path for profitability, which can involve careful siting, development of knowledge and skills, and use of alternative revenue streams (Love et al. 2015). Moreover, economies of scale, alternative business models, and other creative ways to increase income and reduce expenses such as producing inputs on-site or procuring items for free can affect cash flow and help an aquaponics operation be profitable (Goodman 2011). Economic advantages of soilless culture systems include a potentially fast and flexible soilless cropping period, which allows growers to quickly change production to take advantage of market conditions. It is also important to note that the hydroponic system would last through multiple seasons without the need to amend the soil with fertilizer or organic matter.

9.3 Matching Needs of Refugees and Hosts with Frontier Agriculture Technologies

The MENA region faces two large challenges. First, the increasingly water-scarce region applies 85% of its water in agriculture and second, the recent escalation of the global refugee crisis which, to a large extent, is a MENA crisis. There is a need for increased intake of nutritious food, livelihoods, and jobs for a large share of the more than 18 million adult and youth population living in refugee-like situations in

MENA. It is necessary for the protracted situation to be addressed through the development lens to provide solutions that reactivate the lives and skills of the displaced populations. Moreover, the humanitarian system is under pressure and cannot provide enough resources to meet the needs of forcibly displaced people in the MENA region and beyond. The remainder of this report attempts to merge two agendas: food insecurity among the refugees in a water-scarce region and find solutions through innovative technologies.

Given that water and arable land are scarce in MENA, one way of increasing food production is through frontier agriculture. Hydroponics and aquaponics are climate-smart, innovative, and effective technologies that can produce nutritious food with less water (at least 80%) without requiring arable land. Hydroponic systems are easy to operate and can be installed for small-scale use in homes and community cooperatives to large-scale, commercial farms. Due to the adaptability and flexibility of hydroponics and aquaponics to most environments, and their ability to provide additional nutritious food and marketable produce beyond the capacity of arable land, these technologies are being employed in some of the most challenging areas in MENA, such as in the Palestinian Territories. The selection of the type of hydro/aquaponic system depends on the access to inputs and the level of creativity to produce, reuse, or upcycle inputs. Since the technology is flexible and adaptable to local conditions, the simplest system can jump-start or supplement existing food production. It is a solution that can be introduced in places that previously had no or very limited food production.

The basic inputs to hydro/aquaponics are available or acquirable in all countries in MENA. Hydroponics systems provide high-cost savings on water, land, fossil fuels, and chemical purchases compared to traditional farming. The startup and operating costs entirely depend on the type of system chosen and level of complexity. The more advanced and complex the system, the higher the startup and operating costs. There also tends to be less waste with hydroponics and overall better resource management. This system allows for more crop cycles in a year than traditional farming and more high-value crops in some areas.

We developed a flexible decision matrix that can be used as a tool to determine which type of system would be suitable depending on the local conditions of the growing site. The decision matrix in Table 9.1 is a guide to systematically identify, analyze, prioritize, and compare different systems under consideration for implementation in frontier agriculture. The decision matrix presents the technologies discussed in this chapter and ranks them using a Likert-type scale on a variety of attributes: water use, energy use, technological complexity, maintenance, startup costs, financial sustainability, and mobility. Given that each situation requires a different set of social, ecological, and economic considerations, there may not be one single most effective technology for all applications, but hybrids can be constructed to meet specific needs of people, enterprises, and communities.

While advanced hydro/aquaponic systems may be appropriate for some regions, simplified hydroponic systems that are feasible with minimal training and a small initial investment are preferable for refugees and host communities in MENA. Though the yields from simplified systems are lower than advanced systems,

Table 9.1 Decision matrix for water-saving technologies (Source: Authors' elaboration)

Technology	Food	Water use[a]	Energy use	Technological complexity	Maintenance	Start-up costs	Financially self-sustaining	Mobility
Wick systems	Crops	Low	None	Simple	High	Low	High	Low-high
Deep water culture	Crops	Low	Medium	Medium	Low	Med-high	Medium	Low
EBB & flow	Crops	Low	Low-high	Complex	High	Med-high	Low	Low
Drip method	Crops	Low	High	Complex	Low	Med-high	Low	Low
Nutrient film technique	Crops	Low	High	Complex	Med-high	High	Medium	Low
Aquaponics	Crops, fish	Low	Low-high[b]	Complex	High	Med-high	Low	Low
Aeroponics	Crops	Low	High	Complex	High	High	High	Low

[a]Open systems recirculate water, closed systems do not recirculate water
[b]Depending upon pump size and heating requirements. Aquaponics requires a constant electrical source or backup energy (battery, generator)

low-tech systems outperform conventional farming methods and use at least 80% less water. Initially, a needs assessment should be conducted at the local community or individual level to identify and rank the priorities and objectives, which can be used to select an adequate hydroponic system or to design the appropriate system. Regardless of the system chosen, this technology can provide important social, economic, and nutritional benefits.

We propose a three-pronged approach using hydroponic farming systems to address some of the existing needs by providing opportunities for those forcibly displaced, particularly those most poor and/or vulnerable, and their hosts. There are groups with more needs than others, these include refugee women in Lebanon and Jordan that previously worked in agriculture and as housekeepers. They were the most food insecure, had the lowest cash incomes, and the majority were not engaged in paid work. Social barriers, education, skill matches, and household responsibilities seem to prevent many women from participating in the labor markets. Women and girl refugees, and women and girls in host communities in the case of Djibouti, face low education levels, health constraints, and limited access to economic opportunities.

Besides contributing to food security, water-saving agriculture technologies and innovations are ways to improve livelihoods, provide jobs and economic integration with skills, and human capital upgrading for both host and forcibly displaced populations in MENA and those most in need (see above). The three prongs focus on:

- Increasing access to nutritious food
- Improving livelihoods, providing jobs, and supporting economic integration and entrepreneurship
- Enhancing skills

First, increase access to nutritious food: most refugees are food insecure and have a Vitamin A deficiency. Less than 10% of the refugee population in Lebanon and Jordan are food secure. Moreover, different nutritious food items (fruits, vegetables, eggs, meat) are not consumed by refugees on a regular basis. In Djibouti, both refugees and rural host communities are food insecure. The WFP and UNHCR assessment in the refugee camps of Holl Holl and Ali Addeh reports figures of 66% and 44%, respectively. Also, the host communities around the two camps are food insecure; 62% and 44%, respectively (see more in Verner et al. 2017).

The simplest systems in hydroponics, such as the deep water culture Kratky Method and wick bed systems, do not require electricity or land and need a fraction of the water required in open field agriculture. Hydroponic systems can grow a wide variety of fruits and vegetables, especially leafy greens—which grow fast and provide leaves within a few weeks—that help address Vitamin A deficiency. If the primary priority is to address food insecurity among refugees and host communities, households can be trained to maintain the simplest hydroponic systems using basic materials such as buckets and local rocks. Conversely, if the overarching goal is to increase economic activity among refugees and increase incomes, a large NFT system can be constructed at the community level, in which case households can consume from the production and the surplus can be sold in the local market or beyond.

Second, improve livelihoods, providing jobs and supporting economic integration and entrepreneurship: job opportunities need to be created for both displaced populations and host community populations to reduce rampant poverty and vulnerability. Many forcibly displaced and host populations lack jobs and income, which is one of the main reasons as to why they face nutritious food insecurity and poverty as mentioned above. Hydroponics provides different types of employment. Based on field observations, the wicking bed systems used by women in Palestine provided one part-time job per unit for self-consumption and the surplus produce is sold to the market. These women only need to work 2–3 h a day maintaining the system and 2–3 days per week. For larger-scale commercial operations, it is difficult to obtain data on employment, costs, etc. as it is private information, however, evidence shows that using a DWC or NFT system to grow leafy greens on one acre of land provides approximately 18–22 full-time jobs on average.

Hydroponics provides an opportunity to promote entrepreneurship. There is also potential for production that exceeds individual needs, which could lead to the creation of local markets for such produce and additional jobs. The revenue generated by selling excess production could turn into an important source of income for refugees and allow them to meet other basic needs. Other entrepreneurial opportunities not directly related to hydroponics may arise, especially when the refugees can combine other skills with their training on these systems. For example, they can contribute to a higher level in the value chain, such as producing dried blueberries or essential oils, or create inputs to hydroponics such as upcycling materials or creating hydroponic fertilizer. There are also opportunities for refugees to collaborate with host communities. For example, based on field observations in the Palestinian Territories, a group of entrepreneurs in a village near Ramallah secured contracts with prospective restaurant clients in advance of constructing a hydroponics farm.

And third, enhance skills: skills are a key to increase economic integration and expand the private sector. Training and knowledge acquired in hydroponic operations are a way to upgrade human capital, which is transferable to other locations, including the home country after conflict recedes and reconstruction begins. Refugees who return to their origin communities or relocate to other countries will bring the practical knowledge with them and potentially start new hydroponics operations. The training process and increase in human capital may empower refugees to find or create employment or other income-generating opportunities, potentially related to hydroponics. For example, some may choose to work in education in a related field to hydroponic farming and others may choose to work in another part of the value chain, such as producing hydroponic fodder for livestock. Training can also provide social capital to create social enterprises.

9.4 Conclusion

In this chapter we discussed how Frontier agriculture that comprises climate-smart and water-saving agricultural technologies such as hydroponics and aquaponics can improve the livelihoods and well-being of refugee communities and other vulnerable communities, including their host communities, who are often equally food insecure and poor. Frontier agriculture reduces the pressures that host communities experience on their water and other resources due to influxes of refugees. Frontier agriculture can leverage scarce resources, such as water and arable land, and promote inclusive economic activities that increase access to nutritious food, improve livelihoods, create jobs, promote entrepreneurship, enhance skills, and build social cohesion. Frontier agriculture can also contribute to improved overall well-being and nutritional status of people, assist in building community, and support recovery from the loss of assets and from trauma related to fragility and conflict.

While advanced hydro/aquaponic systems may be appropriate in some locations, simplified hydroponic systems that are feasible to implement with minimal training and a small initial investment may be a solution for starting up a food production system for refugees and host communities. Experience suggests that small-scale hydroponic and aquaponic projects targeting vulnerable populations can be implemented rather quickly and produce meaningful results within a short timeframe.

The impacts and benefits of frontier agriculture on food security and livelihoods may vary based on local growing conditions, local market factors, and type of growing system(s) employed. Further research could analyze in more detail crop-yields feasibility and economics in different geographical and local contexts, including growing conditions, labor requirements, input prices, and crop prices. This research can provide a valuable resource to farmers, including refugees, interested in hydro/aquaponics food production.

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